

**NAVAL SHIPS' TECHNICAL MANUAL**

**CHAPTER 531, VOLUME 3**

**DESALINATION -  
REVERSE OSMOSIS  
DESALINATION PLANTS**

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**NOTE**

THIS CHAPTER HAS BEEN REFORMATTED FROM DOUBLE COLUMN TO SINGLE COLUMN TO SUPPORT THE NSTM DATABASE. THE CONTENT OF THIS CHAPTER HAS NOT BEEN CHANGED.

## CHAPTER 531

### DESALINATION, VOLUME 3 REVERSE OSMOSIS DESALINATION PLANTS

#### SECTION 11. REVERSE OSMOSIS

##### 531-11.1 INTRODUCTION

531-11.1.1 GENERAL. Navy reverse osmosis (RO) desalination plants are designed for service where low-pressure steam or waste heat is unavailable or the quantities are insufficient to operate distillers. As with vapor compression distillers, RO units require only electrical power to operate and, therefore, are well suited to both diesel- and gas-turbine-powered ships. Since the RO process is energy efficient, it can be used as a backup source of freshwater on ships that have available steam.

531-11.1.2 DEFINITIONS. Terms used in this volume are defined in [Appendix A](#).

531-11.1.3 SHIPBOARD SERVICE. Reverse osmosis desalination can be used wherever sufficient electrical power is available. A preproduction 9,000-gallon-per-day (gpd) RO unit was installed on board USS FLETCHER in 1988. The design for this plant has been revised to make it fully Navy qualified and to permit quantity production.

##### 531-11.2 PRINCIPLES OF OPERATION

###### 531-11.2.1 THEORY.

531-11.2.1.1 In the late 1970's, a process of directly desalting seawater without the use of heat or a phase change became a practical commercial process. This process, known as reverse osmosis, revolutionized the desalting industry. High-quality water could now be produced at substantially lower energy costs and with substantially less complexity than with conventional distillation systems. The RO process can be thought of as similar to the conventional filtration process - pressurized seawater is passed over a semipermeable membrane that passes pure water but excludes salt species. There are, however, three important differences between RO and conventional filtration processes:

- a. Osmotic Pressure. In the RO process, a natural osmotic pressure exists between the saline and the pure water sides of the membrane. For seawater RO, an osmotic pressure of 350 to 400 pounds per square inch (psi) exists across the membrane, requiring fairly high pressures (700 to 1000 psi) of operation. Conventional filtration processes typically operate from 10 to 25 psi.
- b. Crossflow Operation. In the conventional filtration process, all the process fluid (seawater) normally passes through the filtration media. In the RO process, the process fluid passes over the membrane, but only a small portion (20 to 30 percent) passes directly through it. This allows the salt to remain in the concentrating feed solution, which is discharged overboard. The membrane is therefore free of rejected substances. In contrast, the conventional filtration process retains the rejected material, requiring repeated filter replacement.
- c. Particle Size. In the conventional filtration process, the filter media acts as a sieve, retaining particles as a

result of size and spatial incongruities. In the RO process, ions (charged molecular particles) are separated because of their limited diffusion through the membrane. Particulates as such cannot pass through the membrane mechanically unless the membrane is defective.

531-11.2.1.2 The term reverse osmosis was developed because the process is often thought of as the reverse of the natural process of osmosis ([Figure 531-11-1](#)). If two solutions having different concentrations of solute are separated by a semipermeable membrane (permeable to the solvent but not to the solute), solvent from the weaker solution tends to pass through the membrane, decreasing the concentration of the stronger concentrated solution. The equilibrium pressure head developed by an increase in column height is called the osmotic pressure. This process is known as normal osmosis. (A glossary of applicable terms can be found in [Appendix A](#)).

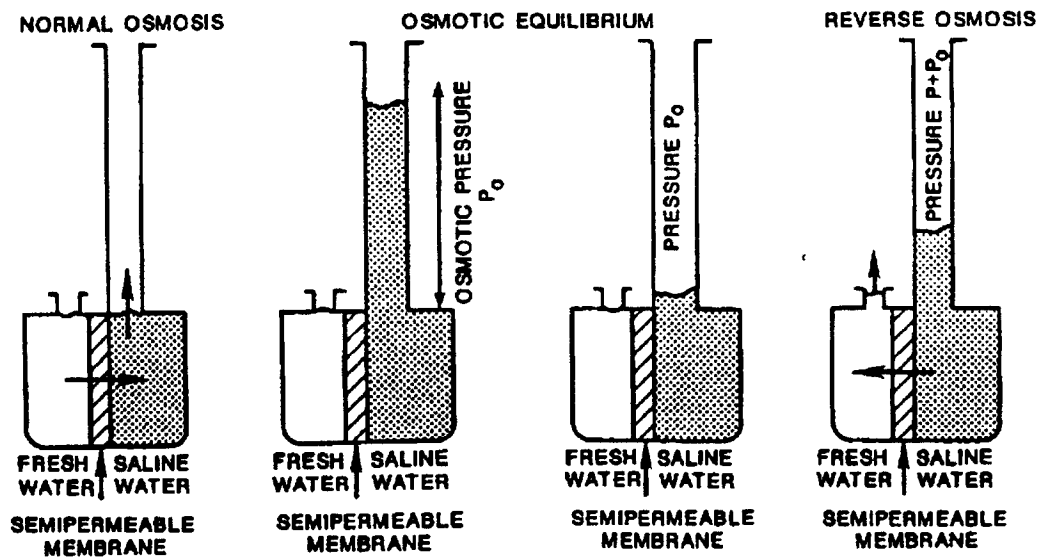


Figure 531-11-1 Normal Osmosis, Osmotic Equilibrium, and Reverse Osmosis

531-11.2.1.3 If the weaker solution is pure water (solvent) and the concentrated solution is seawater, the resulting osmotic pressure will be about 350 psi. The process can be reversed by applying pressure to the seawater in excess of the osmotic pressure. Water will then pass through the membrane from the concentrated side to the weaker side. The membrane rejects the sea salt and dissolves it back into the remaining seawater.

531-11.2.1.4 The greater the difference between the applied pressure and the osmotic pressure, the faster the water will permeate the membrane and the purer the permeated potable water will be. In practice, a pressure of 700 to 1000 psi is required to obtain an acceptable flow of water through the membrane.

531-11.2.1.5 The **solution-diffusion** theory, which as its basis is supported by actual operational data, helps to explain membrane operation. This theory proposes that the water and salt are dissolved directly into the membrane from the saline water side. Their mechanisms of passage through the membrane, however, are distinctly different. The salt diffuses through the membrane from the seawater side to the freshwater side at a given rate consistent with the principles of diffusion. That is, the migration of salt through the membrane is proportional to the difference of the salinity between the saltwater and freshwater on adjacent sides of the membrane. It is theorized that this diffusive process is a function of the electrical interaction of the salt ions and the active ionic groups in the polymeric structure of the membrane. Pure water, on the other hand, passes through the membrane under hydraulic pressure -- its rate of permeation being directly proportional to the hydraulic pressure drop across

the membrane. A good RO membrane provides maximum waterflow with very low salt diffusion. Salt separates as the waterflow rate through the membrane greatly exceeds the salt diffusion rate. This **solution-diffusion** concept can be demonstrated on any RO plant simply by increasing the pressure. The permeation rate will increase, and the permeate salinity will appear to decline. What actually happens is that the salt diffusion rate remains constant, and the greater water permeation rate results in a greater salt dilution.

**531-11.2.2 MEMBRANE MODULE.** The RO membrane must be able to withstand the operating pressure while allowing the purified water to pass through with the minimum resistance. This is usually achieved in practice by supporting the membranes in various configurations known as elements, inside a pressure vessel. The whole unit is known as a module. Various types of membrane element configurations have been developed in an effort to obtain a high surface area of membrane in a small volume. Several types of membrane elements are available commercially in a variety of membrane materials. The two main element types are hollow fiber and spiral wound. Only the spiral-wound configuration, which is used in Navy RO systems, is discussed here.

**531-11.2.3 SPIRAL-WOUND ELEMENT.** Membranes used for seawater service are made of thin-film composites of an aromatic polyamide. The membrane consists of a central permeate carrier (product water support backing) covered on both sides by the semipermeable membrane with porous layer support ([Figure 531-11-2](#)).

**531-11.2.3.1** The layers are glued along three edges to prevent feed from contacting the permeate. The fourth edge is attached to a central permeate collection tube that is perforated inside the seal area. A coarse mesh seawater flow spacer placed outside the sandwiched layers enables the seawater to flow across the membrane surface. The whole assembly is then rolled around the permeate freshwater collection tube and covered with a glass fiber outer wrap for structural strength (not shown). The completed rolled element is then fitted with antitelescoping spider-webbed hubs (not shown) on each end of the cylindrical element. These spider-webbed hubs have grooves for sealing one end of the element inside the pressure vessel, using a U-cup seal.

**531-11.2.3.2** In operation, feed is pumped under pressure into one end of the module and flows over the membrane surface through the mesh flow spacer. Permeate passes through the membrane and flows into the central permeate support tube by way of the central permeate backing. The concentrated seawater (brine) leaves the module through the end opposite the feed inlet.

**531-11.2.4 MEMBRANE MATERIALS.** The selection of membrane materials determines the water flux and salt rejection characteristics of the membrane. At this time, all Navy RO units use polyamide membrane material.

**531-11.2.5 MEMBRANE PERFORMANCE.** The two primary performance characteristics of RO membranes are salt rejection and water flux. These characteristics are affected by feed temperature, pressure, and salinity.

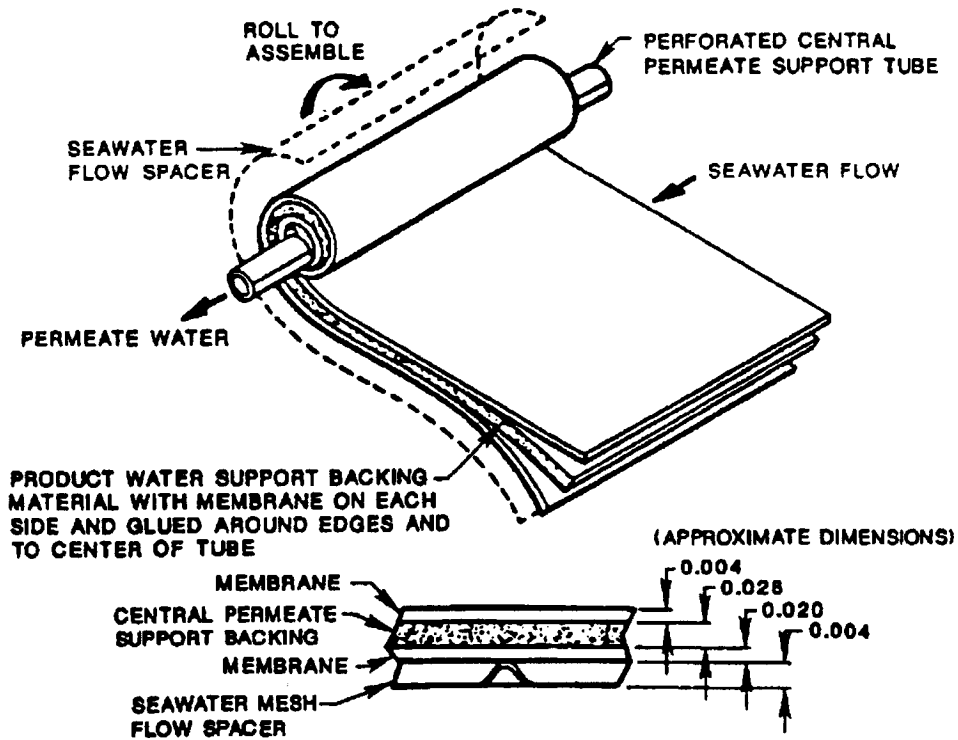


Figure 531-11-2 Spiral-Wound Membrane, Unrolled

531-11.2.5.1 Salt Rejection. Salt rejection is the inverse of salt passage. Salt passage can be defined as the product salinity divided by feed salinity expressed as a percentage. The percentage of salt rejection is then expressed or determined by subtracting the salt passage percentage from 100. In general, RO membranes severely restrict the passage of most dissolved molecules while permitting the relatively free passage of water.

531-11.2.5.1.1 The currently available RO units usually yield a product water containing less than 1 percent of the total dissolved solids (TDS) entering with the seawater feed. This results in a permeate quality of less than 500 parts per million (ppm) salinity, which meets the water quality requirements of the Naval Medical Command (BUMED Instruction 6240.3C, **Standards for Potable Water**). Higher water qualities are easily achieved by staging the membranes.

531-11.2.5.2 Effect of Temperature. Raising the temperature of the feed increases the output of a module. A convenient rule of thumb is: A temperature rise of 2° F will increase product rate by approximately 3 percent.

531-11.2.5.3 Effect of Pressure. The permeate rate of an RO system is proportional to the applied operating pressure less the osmotic pressure. The effective osmotic pressure is determined by the average concentration difference between feed and reject brine. The osmotic pressure of seawater is approximately 350 psi. The effective driving force of a system operated at 800 psi would be 450 psi.

531-11.2.5.3.1 From the standpoint of product purity, a high feed pressure is desirable. Flux is proportional to the effective pressure difference (that is, applied pressure minus the osmotic pressure). Raising the pressure therefore increases water flow without increasing salt transfer, resulting in a purer product. Refer to paragraph [531-15.2.4](#) for further explanation.

531-11.2.5.4 Recovery Ratio. The recovery ratio is the percentage of feed recovered as product. In general, a large recovery ratio is desired. The value is limited by feed scaling, however, and by any increase in the average feed salinity, which increases the osmotic pressure. An increase in osmotic pressure increases product salinity and decreases element productivity. The recovery ratio is important in RO unit design because it affects membrane performance and determines the size of the feed and reject streams and all related process components.

531-11.2.6 SINGLE- AND MULTI-PASS SYSTEMS. Unlike the distillate produced in both low-pressure and vapor compression distillers, which contains less than 5 ppm of TDS, or boiler quality water, the permeate produced in a single-pass RO unit contains 350 to 500 ppm TDS. Although single-pass permeate is acceptable as potable (drinkable) water, it does not meet the requirements for use in boilers.

531-11.2.6.1 A new RO membrane normally rejects 99 percent of the dissolved solids, allowing only 1 percent of these solids to pass through with the pure water. For example, seawater with 35,000 ppm of dissolved solids as the feed to a single-pass RO unit, will produce a permeate of 350 ppm ( $35,000 \times 0.01 = 350$ ) TDS. To produce boiler quality water with an RO unit, the permeate (350 ppm TDS) from the first stage is used as the feed to a second stage to produce permeate with 3.5 ppm ( $350 \times 0.01 = 3.5$ ) TDS. A third membrane stage can be applied to produce water with less than 0.1 ppm.

531-11.2.6.2 An RO unit can produce boiler quality water by either continuous or batch processing:

- a. Continuous. Depending on the quality of water desired, the continuous process requires one or more additional stages. In a two-stage RO unit, the permeate (350 ppm) from the first set of RO modules becomes the feed supply to a second pump and second set of RO modules.
- b. Batch. In the batch process, the same RO modules are used to make both potable and boiler quality water, and therefore only potable or boiler quality water can be provided at any one time. When boiler quality water is desired, the feed to the RO unit is switched from seawater to freshwater from the ship's storage tank. Although this method reduces the initial cost of the RO unit, it is much less flexible since the production of potable water stops while boiler quality water is being produced.

531-11.2.7 PRETREATMENT. Pretreatment is the part of the design that determines the long-term performance of the RO unit. Adequate pretreatment of the seawater is essential to the successful and economic operation of the unit. Fouling of an RO membrane causes rapid flux decline. This results in loss of productivity due to frequent shutdowns for membrane cleaning or replacement. Pretreatment will eliminate or minimize fouling, of which there are three types:

- a. Membrane element plugging
- b. Membrane scaling
- c. Colloidal (biological) fouling.

531-11.2.7.1 Before entering the RO unit pretreatment system, the seawater is filtered through a sea chest strainer that removes marine animals and large debris. A duplex strainer is typically used to remove particles larger than 1/32 inch.

531-11.2.7.2 In the RO unit, the seawater is first cleansed of the larger and heavier suspended particles by a cyclone separator. This removes most particles larger than 75 microns. The remaining suspended particles down

to 3 microns are removed by a series of cartridge filters, each with elements consisting of successively smaller filter media. Some ship classes that operate in heavily silted waters close to shore remove particles down to 1 micron.

**531-11.2.8 POSTTREATMENT.** The permeate for potable use is brominated to ensure that it is free of harmful organisms. Boiler quality water is not so treated.

**531-11.2.9 CONTROL.** Instrumentation and control consists of product water quality monitoring (conductivity), product water and brine flow measurement, and cartridge filter differential and pump discharge pressure monitoring. Control by the brine restrictor valve is manual. Protective devices are limited to low- and high-pressure switches on the pump suction and discharge piping, respectively, with motor interlocks and relief valves on the high-pressure pump discharge and permeate lines. This has proved to be a simple and very effective system.

## **SECTION 12.**

### **DESCRIPTION**

#### **531-12.1 COMPONENT ARRANGEMENT**

##### **531-12.1.1 GENERAL**

**531-12.1.1.1** The following paragraphs describe the component arrangement and flow paths for a typical 9,000-gallons-per-day (gpd) reverse osmosis (RO) unit. Since all RO units use basically the same components, this description and the flow schematic ([Figure 531-12-1](#) and [Figure 531-12-2](#)) for the 9,000-gpd RO unit have been chosen.

##### **531-12.1.2 NORMAL MODE**

**531-12.1.2.1** After the ship-installed duplex strainer, the entering feed passes through a thermostatically controlled heater that maintains a feed temperature above 35° F. The feed next enters the centrifugal separator where the larger and heavier debris, sand and silt, is removed to prevent premature plugging of the cartridge filters. From the centrifugal separator, the feed then flows through the three-way feed selector valve (V-2), positioned for normal operation. The feed then enters the cartridge filters, 20- and 3-micron filter media in series, to remove the remaining suspended particles that could foul the membrane.

#### **NOTE**

Some designs may incorporate a feed booster pump to compensate for the pressure loss through the filter system.

**531-12.1.2.2** The cleaned feed next enters the high-pressure (HP) pump, which increases the pressure to approximately 800 psi.

**531-12.1.2.3** From the HP pump, the discharge enters the RO modules. As the HP feed seawater passes through the module over the membranes, it becomes more concentrated as a portion of it permeates through the mem-

brane as freshwater. This remaining concentrated feed (brine) is then discharged from the RO module. The brine then flows through the parallel path of the brine restrictor valve (V-5) and pressure-reducing coil that control the system pressure. Finally, the brine flows through the brine flowmeter to the overboard discharge.

531-12.1.2.4 The permeate leaves the module from the center collection port and passes by the conductivity cell, which measures salinity. The permeate then flows through the permeate flowmeter and to the three-way dump valve. If the permeate is out of specification, (that is, greater than 1,000 micromhos/cm) it is automatically dumped to the bilge. Acceptable quality permeate is diverted to the totalizing flowmeter to register production. Freshwater is subsequently brominated and sent to the potable water storage tanks.

531-12.1.3 FLUSH AND CLEANING MODE. The following paragraphs describe the flow path when the RO unit is to be flushed for the lay-up or clean modes. For long-term shutdown the entire RO system is laid up with debrominated freshwater to protect system components from biological growth and corrosion.

531-12.1.3.1 The feed shutoff valve (V-1, [Figure 531-12-1](#)) is secured before the freshwater stop valve (V-3) and freshwater shutoff valve (V-4) are opened. The backflow preventer (BFP-1) prevents any fluids from entering and contaminating the freshwater line. The freshwater from the ship's storage tanks, which has been brominated in accordance with Navy health requirements, is passed through an activated carbon filter for bromine removal. (Bromine can damage the polyamide membrane used in the RO system.) The freshwater then flows through the three-way feed selector valve (V-2) positioned for freshwater flush. The freshwater follows the same path as it would in the normal mode, filling the system with freshwater.

531-12.1.3.2 If the membranes are heavily fouled (as evidenced by a performance decline), they can be cleaned by recirculating a cleaning solution, introduced in the 3-micron filter housing, through the RO modules and system. The freshwater recirculation valve (V-10, [Figure 531-12-2](#)) is opened and the brine shutoff valve (V-7) is closed to provide a closed system for recirculating the chemical solution. The control panel is set for the clean mode, and the chemical solution recirculates throughout the RO unit for a predetermined time set by the controller.

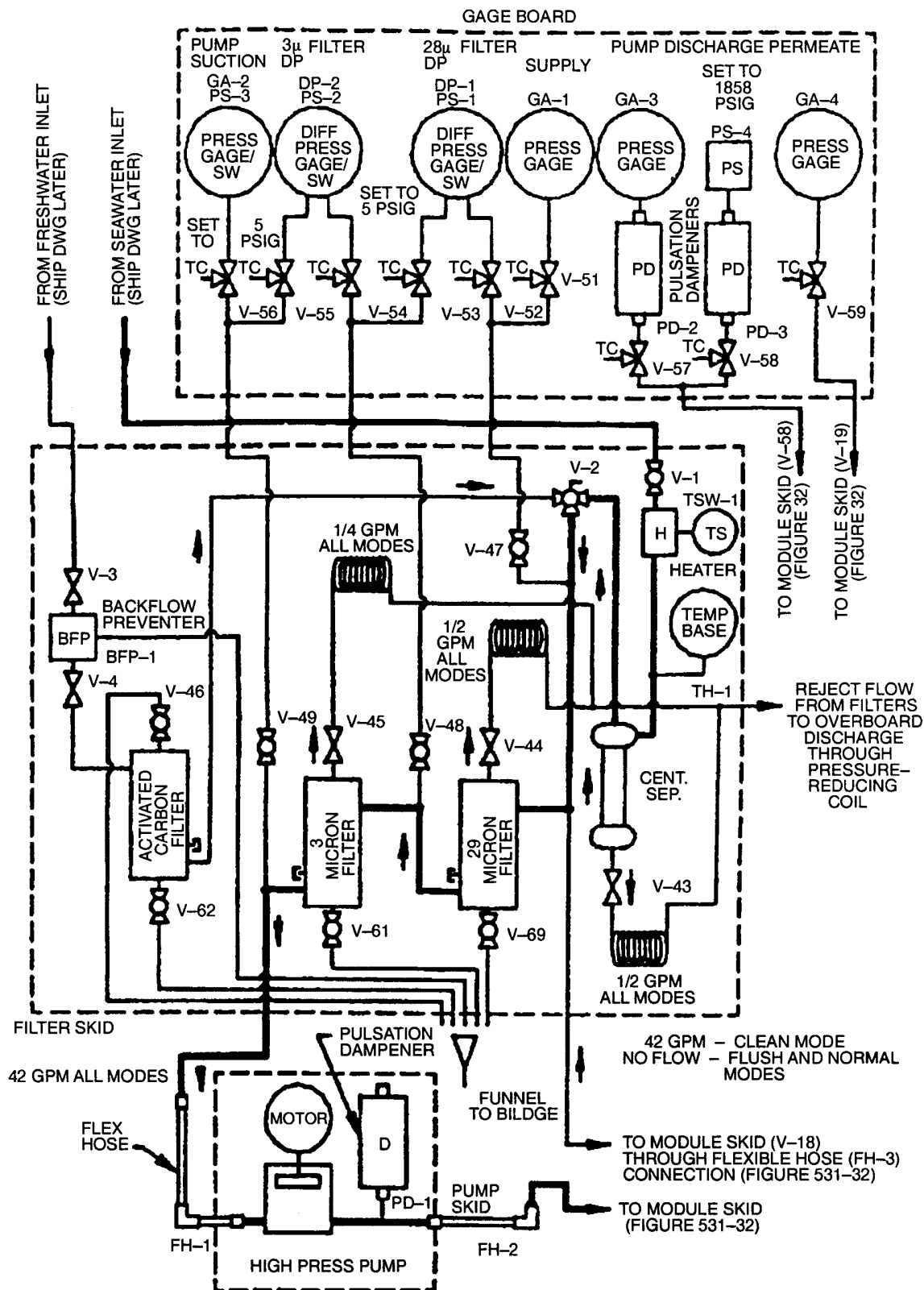


Figure 531-12-1 Filter and Pump Skids Piping Schematic

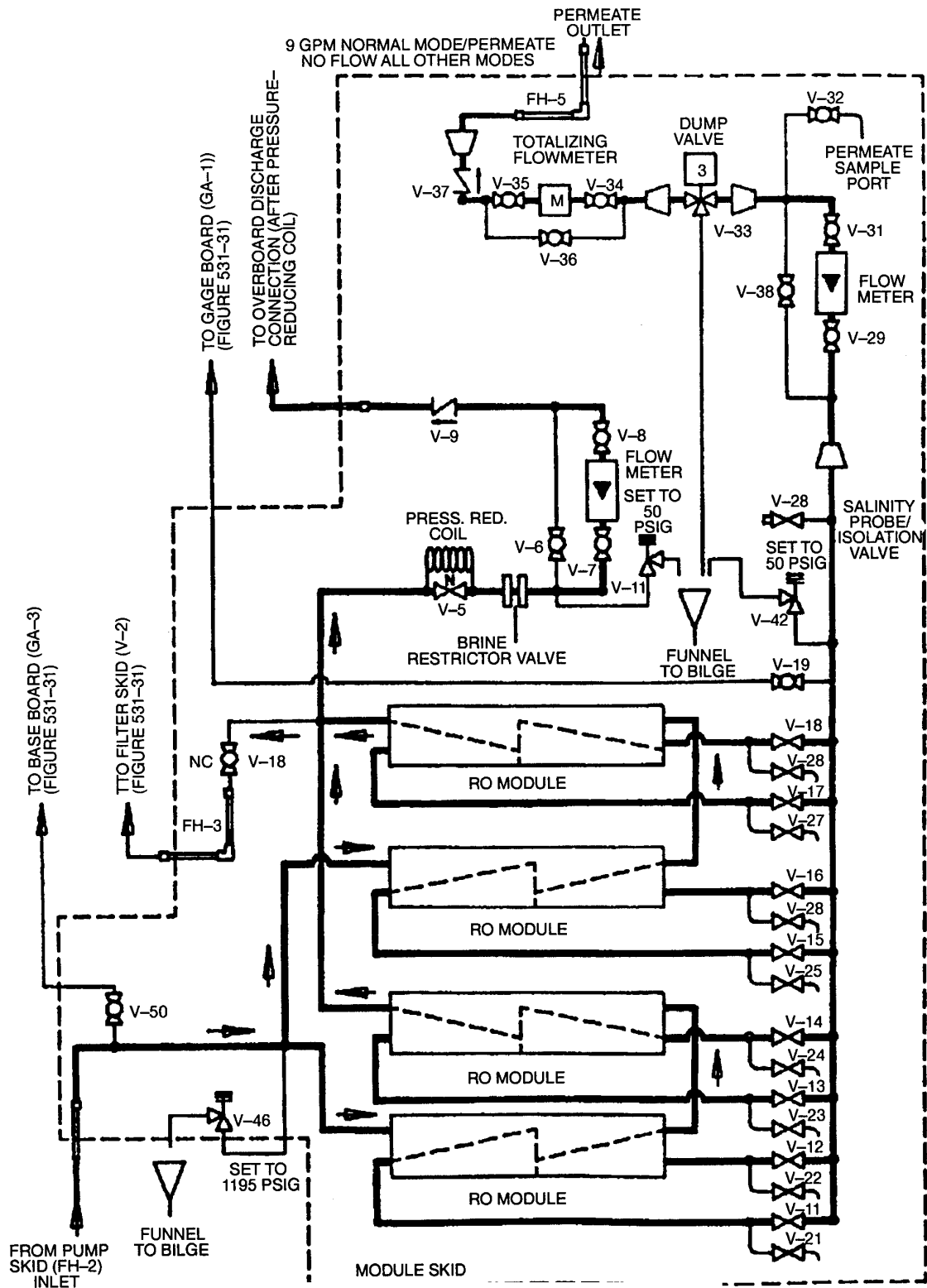


Figure 531-12-2 Module Skid Piping Schematic

## **531-12.2 COMPONENT DESCRIPTION**

**531-12.2.1 GENERAL.** The following paragraphs describe RO unit components. Not all of these components are used on every RO unit. Some components are supplied by the ship, and others are not used because of variations in design.

### **531-12.2.2 FILTER SYSTEM**

**531-12.2.2.1 Duplex Strainer.** The duplex strainer, either furnished with the RO unit or supplied by the ship, is the first step in removing large pieces of debris from the seawater.

**531-12.2.2.2 Centrifugal Separator.** After the duplex strainer, heavy suspended particles (sand and silt) are removed by centrifugal force. The larger and heavier solids along with a small amount of seawater are removed from the bottom of the separator through a continuous drain. The remaining flow of cleaner seawater continues upward through a pipe in the center of the device and then to the heater or cartridge filter. The centrifugal separator is designed to remove 98 percent, by weight, of separable solids 200 mesh (74 microns, or 0.003 inch) and larger.

**531-12.2.2.3 Heater.** The heater prevents freezing on the freshwater side of the membrane modules when the seawater temperature is below 32° F. Because of its high salinity, seawater freezes below 28.6° F. If the seawater temperature is below 32° F, the permeate (which is low in salinity) will freeze as it emerges from the permeate side of the membrane. The heater contains a built-in thermostat that activates the heating element when the seawater temperature drops below 35° F and deactivates the element when the temperature rises above 38° F. Since the RO unit is designed for a rated capacity at feed temperatures as low as 35° F, the heater also ensures full rated production capacity under all anticipated operating condition.

**531-12.2.2.4 Cartridge Filters.** Filtration of the seawater minimizes the potential for membrane fouling. Cartridge filters are provided in a staged sequence to ensure maximum filter efficiency. Successively finer filter elements are installed in each subsequent filter housing. In all cases, differential pressure gages and switches measure pressure and warn the operator (by alarm) when the pressure drop across a filter exceeds the set pressure.

**531-12.2.2.5 Activated Carbon Filter.** The activated carbon filter removes the bromine or chlorine, which is harmful to the polyamide membrane, from the freshwater in the storage tank before it is used for flushing or cleaning the RO unit.

**531-12.2.2.6 Backflow Preventer.** A reduced-pressure backflow preventer is installed anytime a connection is made between a potable water system and any nonpotable water system. It is designed to protect the potable water system against the backflow of fluids to the freshwater tanks.

**531-12.2.2.7 Feed Booster Pump.** If seawater cannot be supplied from the ship with enough pressure to overcome the flow resistance through the components of the filter system and still meet the suction pressure requirements of the HP pump, a feed booster pump is installed. Usually, a centrifugal pump rated for the design flow at a pressure of 50 psig will meet the need. This ensures that a positive pressure is maintained at the suction of the high-pressure pump and that the low-pressure shutoff switch setpoint is satisfied.

### 531-12.2.3 HIGH-PRESSURE PUMP SYSTEM

531-12.2.3.1 High-Pressure Pump. The HP pump increases the pressure of the seawater to 700 to 1000 psi to provide the driving force for the RO process. Positive displacement (reciprocating) pumps are used.

531-12.2.3.1.1 Larger RO units have TRIPLEX (three-plunger) pumps. These pumps consist of the liquid end (which actually pumps the seawater) and the power end (which converts the rotational motion provided by the motor into reciprocating motion). As with all positive displacement pumps, they discharge a given volume of fluid for each stroke of the plunger. The volumetric flow depends on the diameter of the plunger and the length of the stroke. The quantity of fluid is determined by the rpm of the pump when it is operating. To obtain the proper design flow, the pump is V-belt driven, using sheaves with the appropriate pitch diameters to achieve the correct ratio and corresponding speed.

531-12.2.3.1.2 Smaller RO units use axial-piston-diaphragm pumps that convert rotary motion of an input shaft to an axial reciprocating motion of three or more pistons. The motion is converted by a wobble (revolving swash plate) plate. The wobble plate moves the oil-filled pistons, which in turn move the diaphragms. When the diaphragms move back, seawater enters the pump through the inlet valves. As the diaphragms move forward, the seawater is pumped through the outlet valves.

531-12.2.3.1.3 Positive displacement pumps are ideal for RO service since they supply the required high pressure at constant flow and at relatively high efficiencies (upwards of 90 percent). Discharge pressure is determined by control of the restrictor valve. The reciprocating motion of the plungers causes structural vibration and pressure pulsations in the fluid system. The vibration is reduced by using mil-spec vibration and shock isolation resilient mounts. To minimize airborne noise transmission, the pump may be covered by a noise attenuation housing. The fluid pulsations are reduced by pulsation dampeners and isolated by flexible hose connections at the suction and discharge of the pump.

531-12.2.3.2 Motor. The high-pressure pump is driven by an induction motor using belt drive to achieve the correct speed for the design flow. The motors are designed to operate at 440 Vac and for continuous duty.

531-12.2.3.3 Pulsation Dampeners (Accumulators). The reciprocating motion of the HP pump creates pressure surges in the downstream piping. A pulsation dampener installed near the pump in the discharge (and sometimes suction) piping absorbs these cyclical pressure pulsations. Pulsation dampeners consist of a nitrogen-charged rubber bladder inside a pressure vessel. For effective dampening, the charge pressure is approximately 2/3 the pressure of the system in which they are located. Without pulsation dampeners, the pressure surges from these undampened stresses would cause fatigue failures in the pump, membranes, and associated equipment.

### 531-12.2.4 MODULE SYSTEM

531-12.2.4.1 RO Modules. The actual process of desalination occurs in the RO modules. The RO module consists of a pressure vessel that contains one or two membrane elements.

531-12.2.4.1.1 Component Overview. The pressure vessels are made from glass-reinforced plastic or suitable corrosion-resistant metal. They are designed to allow easy replacement of the membrane element.

531-12.2.4.1.2 System Overview. As the pressurized seawater flows across the membrane surface, freshwater passes through the membrane as the dissolved salts are rejected. Since the RO modules are connected in series on the seawater side, the seawater becomes more concentrated with dissolved salt as it flows from one membrane element to the next because of the removal of freshwater. The more highly concentrated seawater is discarded as waste (brine) after the last membrane in the series. Freshwater is collected in the permeate support tube along the centerline of the module and discharged from the pressure vessel at relatively low pressure (approximately 50 psi).

531-12.2.4.2 Brine Restrictor Valve Assembly (Pressure-Regulating Valve). The brine restrictor valve is used to set the system pressure. The brine restrictor valve (usually a needle type) is downstream of the membrane modules and is adjusted manually to obtain either the set operating pressure or the desired permeate production rate, depending on how the RO unit is instrumented. Once the desired permeate production has been stabilized, only minor and occasional adjustments of this valve are required. Some RO units use a pressure-reducing coil in parallel with the brine restrictor valve to reduce the pressure drop across the brine restrictor valve and thus reduce the potential noise energy. On some smaller RO units a back-pressure regulator (which uses a spring-loaded piston) is adjusted to the desired back pressure.

531-12.2.4.3 Flowmeter (Rotameter). In-line flowmeters monitor both the brine and the permeate leaving the RO modules. These flowmeters provide a continuous readout of the flow in gallons per minute. The sum of the brine flow and permeate readings indicates the quantity of seawater being pumped by the HP pump.

531-12.2.4.4 Totalizing Flowmeter. The totalizing flowmeter registers the cumulative volume in gallons of permeate being produced by the RO unit and being used by the ship.

531-12.2.4.5 Dump Valve (Divert Trip Valve). The dump valve is a three-way solenoid valve that diverts the permeate from the RO modules to either the bilge or the freshwater storage tank. The available choice depends on the conductivity of the permeate, as sensed by the salinity monitor. The dump valve is designed to provide fail-safe conditions to prevent out-of-specification [above 500 ppm total dissolved solids (TDS)] permeate from entering the freshwater system.

531-12.2.4.5.1 The permeate flows to the bilge when the RO unit is first started. Until the salinity monitor indicates that potable water (less than 500 ppm TDS or 1,000 micromhos/cm conductivity) is being produced, the dump valve cannot be latched magnetically in position to permit flow to the freshwater storage tank. When the criteria for potable water are met, the valve is manually engaged and held in the UP position by a solenoid. This permits potable water to flow to the freshwater tank. If during normal operation the conductivity rises above the 1,000-micromhos/cm setpoint, the salinity monitor de-energizes the solenoid in the dump valve, allowing the handle to drop (unlatch). Normally, a remote alarm is indicated either on the local control panel or on the control console in the control room. This diverts the permeate to the bilge. Only after the problem is corrected or the failed membrane is isolated or replaced can the dump valve be latched.

531-12.2.4.6 Relief Valve. Spring-loaded safety relief valves are used in the brine and permeate system to protect the piping components from overpressure.

531-12.2.5 CONTROL PANELS. RO plant controls and instruments may be arranged into three assemblies:

a. Main control panel

- b. Salinity indicating panel
- c. Gage panel.

531-12.2.5.1 Main Control Panel. The main control panel (MCP) is the central control system for the RO plant. A typical MCP assembly consists of power supplies, switching, indicating, and protective equipment. The main control, gage, and salinity panels are usually mounted in the ship's structure or in an RO module skid. These panels are usually in front of the RO plant modules to simplify operation and maintenance. Any maintenance or repair work to the MCP shall be conducted in accordance with **NSTM Chapter 300, Electric Plant - General**.

531-12.2.5.2 Salinity Indicating Panel. The salinity indicating panel houses the various self-contained indicating assemblies, including the power supply, protective equipment, audible alarm, and salinity level meter modules. It continuously monitors the permeate water conductivity by means of the salinity cell (conductivity probe), mounted in the discharge line upstream of the dump valve. The dump valve is automatically activated by this panel when the permeate water conductivity rises above the preset limit (1,000 micromhos/cm). A complete description, and operating and maintenance instructions for the salinity indicating panel can be found in NAVSEA SN576-AE-MMA-010/00062, **Salinity Indicating Equipment, Installation, Operation, Maintenance and Repair Instructions**.

531-12.2.5.3 Gage Panel. The gage panel consists of pressure gage indicators, pressure switches, an instrument pulsation damper, and a gage valve for the feed supply, pump suction and discharge, and permeate discharge. This equipment is flush mounted on the panel. Differential pressure indicators, with a pressure switch for the alarm, monitor inlet and outlet pressures of the cartridge filters. Additional information on pressure gages can be found in **NSTM Chapter 504, Pressure, Temperature and Other Mechanical and Electromechanical Measuring Instruments**.

531-12.2.6 PROGRAMMABLE LOGIC CONTROLLER. The RO plant may incorporate a programmable logic controller (PLC) rather than conventional relay logic. A PLC is a device that controls a machine or process on the basis of input received from the machine or process, or other input. It performs the same function as a relay panel or other control devices but has the advantage of being programmable. This means that the sequence of operation it controls is established by depressing the appropriate pushbuttons on a control panel. All internal wiring is fixed, and the operations directed by the PLC are fixed in a read only memory (ROM) chip.

531-12.2.6.1 PLC Components. The PLC consists of a central processing unit (CPU), memory, and input/output (I/O) modules. The CPU is the heart of the system. It accepts input from the pressure and temperature switches and the salinity monitor. From this input and preprogrammed instructions stored in the PLC memory, it determines the appropriate output. The I/O modules act as an interface between the PLC and the field function occurring in the process being controlled. The PLC program is designed to be handled easily by people familiar with relay logic.

531-12.2.6.2 Maintenance. The PLC is designed for simple maintenance -- modules are replaced rather than components. Indicating lights identify major diagnostic points. Major policies and instructions pertaining to the maintenance of electronic equipment and safety information can be found in NSTM Chapter 400, Electronics. Subordinate policies and instructions required to implement the policies and instructions of this chapter can be found in NAVSEA 0967-LP-000-0100 through 0967-LP-000-0160, **Electronics Installation and Maintenance Book**.

531-12.2.6.3 Alarms. The PLC is also programmed to activate visual and audible alarms:

- a. A yellow alarm will not shut down the system, but will caution the operator during startup and operation to take corrective action. Yellow alarm conditions are low charge on the PLC battery, high differential pressure across the cartridge filters, dump valve open, and high salinity. Each condition has a yellow indicating light emitting diode (LED). The yellow alarm lamp will light during any yellow alarm condition.
- b. A red alarm will prevent system startup and will shut down the system during operation. Red alarm conditions are high system pressure, low suction pressure to the HP pump, and low water temperature when the heater is disabled. Each condition has a red indicating LED. The red alarm lamp will light during any red alarm condition.
- c. A red or yellow alarm will trigger an audible alarm. Depressing an alarm acknowledge pushbutton will shut off the audible alarm and indicate to the system that the operator is aware of the alarm condition. The associated alarm LED will remain lighted until the condition is corrected and an alarm reset pushbutton is depressed.

**531-12.2.7 ELECTROMECHANICAL RELAY CONTROLS FOR RO UNITS.** Controls for RO units may use conventional electromechanical relays activated by permissive controls. The movable contacts in these relays are hard wired to the motor control circuit. Conventional electromechanical relays require more space and wiring, and offer less flexibility to control changes than do PLC's.

**531-12.2.8 MOTOR CONTROLLER.** The HP pump motor controller is a low-voltage-protection (LVP) type. It will disconnect the motor from the power supply on reduction or loss of voltage. The motor will remain disconnected until the operator restarts the system. Basic LVP motor controller operation and maintenance are discussed in **NSTM Chapter 302, Electric Motors and Controllers.**

**531-12.2.9 PRESSURE SWITCHES AND INDICATORS.** Pressure switches are used to shut off the HP pump and indicate when the cartridge filters need to be replaced. Pressure indicators are panel mounted, are supported with a case, and have operating pressure (indicating) pointers.

**531-12.2.10 TEMPERATURE SWITCHES AND INDICATORS.** A feed heater maintains the incoming seawater temperature above freezing. The heater is actuated by a thermostatic temperature controller that cycles the heaters, as necessary, to keep the water flowing to the HP pump above a specified temperature. The various types of temperature switches and indicators, their operation, service accuracy, and maintenance and adjustments can be found in **NSTM Chapter 504.**

## **SECTION 13.**

### **OPERATION**

#### **531-13.1 INTRODUCTION**

**531-13.1.1 SCOPE.** This section gives information on reverse osmosis (RO) plant operation, including safety precautions and general procedures for starting, running, and securing the plant. Other discussions cover lay-up, operating problems, fouling, permeate purity, and keeping a log.

**531-13.1.2 APPLICABILITY.** The information in this section (and throughout the manual) is intended to supplement, not replace, the detailed operating procedures in the individual plant technical manuals (TM). Correct operation of an RO plant requires that personnel be trained and understand the function and use of all com-

ponents and controls before starting the plant. All operating and maintenance personnel should use the flow diagram in the TM to become familiar with the various flows (feed, brine, permeate, freshwater) throughout the plant. The valve and instrument schedule in the TM will help in locating and identifying the valves and indicators on the plant.

### 531-13.2 SAFETY PRECAUTIONS

531-13.2.1 GENERAL. Incorrect or careless operation of the RO plant can cause personnel injury and equipment damage. The following general precautions apply to all RO plants. Individual plant TM's give additional precautions that apply to specific procedures or equipment. Operating and maintenance personnel shall be familiar with all safety precautions before operating or repairing RO plants.

531-13.2.2 OPERATING PRECAUTIONS. Observe the following safety precautions during plant operation:

1. Make sure all personnel and tools are clear of the plant before initiating the startup procedure.
2. Do not operate an RO plant that has damaged or deteriorated pipes, valves, fittings, gaskets, or hoses. Such operation could result in the sudden escape of high-pressure (HP) water, which could cause injury.
3. Make sure that all pressure relief valve discharges are unobstructed and that the released fluid is conducted to a low-pressure area clear of personnel.
4. Do not operate the RO plant when the dump valve is locked in the normal (up) position (permeate sent to storage). A locked valve will not trip to divert out-of-specification permeate to waste.
5. Keep hands and feet away from rotating equipment. Before starting the RO plant make sure that all belt and coupling guards have been installed.

531-13.2.3 MAINTENANCE PRECAUTIONS. Observe the following precautions when performing maintenance:

1. Before working on the RO plant, shut off all electric power. Close all water shutoff valves, and open all vent and drain lines. Tag out the plant in accordance with OPNAVINST 120.32B, **Standard Organization and Regulations of the U.S. Navy**, paragraph 630.17.
2. Wear a face guard, protective clothing, dust respirator, and gloves when handling and mixing the cleaning chemicals. See individual plant technical manuals for specific handling and mixing procedures.
3. Wear safety goggles when cleaning with compressed air.

### 531-13.3 STARTING THE PLANT - TESTS AND INSPECTIONS

531-13.3.1 OVERVIEW. The following guidelines apply to all RO plants but do not take the place of detailed procedures. All operating personnel shall be thoroughly familiar with the specific startup procedures in the equipment TM for their plant.

531-13.3.2 GENERAL. Perform the following general inspections before and during plant startup:

1. Thoroughly inspect the plant before startup. Check for damaged pipes, valves, and fittings; structural damage; and deteriorated gaskets and hoses.
2. Make sure that all required services are available, including feed, electric power, and an open brine overboard line.
3. Make sure that the flowmeters (rotameters) are clear and that the floats are visible.
4. Check the operation of all manually controlled valves.
5. Make sure that all pumps are free to rotate. If electric leads have been disconnected since the last operation, check the pumps' rotational direction.
6. After the feed valve is opened, and before the unit is started, check the entire RO plant for leaks.

531-13.3.3 RO STARTUP PROCEDURE - NORMAL MODE. The following startup procedure assumes that the filters are in reliable operating condition, the pulsation dampeners are correctly charged, and the HP pump crankcase is correctly filled with oil:

1. Refer to the individual plant TM to make sure that all RO plant and ship valves are in their correct position.
2. With the feed shutoff valve open, check that there are no system leaks, the filter vessels are vented, and the pressure gage at the suction to the booster pump or HP pump reads higher than the required suction pressure.
3. Close the appropriate breaker. Verify that the indicator light on the main control panel is on, indicating that power is available.
4. For units with a programmable logic controller (PLC), depress the start button after the normal mode has been selected. For other units, switch on the booster pump and verify that the suction pressure to the HP pump is adequate. If so, switch on the HP pump.
5. Listen for any unusual noises that may be coming from the HP or booster pumps. If the noises do not disappear in 30 seconds, stop the unit and consult the technical manual.
6. The salinity alarm will be ringing because out-of-product permeate is passing the salinity cell. Move the bell selector switch to the cutout position, and depress the alarm acknowledge pushbutton.
7. Slowly close the brine restrictor valve while monitoring either the HP pump discharge pressure or the permeate flowmeter. Adjust this valve until the correct pressure or flow is obtained.
8. Place the brominator into service, and close its bypass valve.
9. Observe the salinity monitor. The conductivity should steadily decrease. When the conductivity drops below 1,000 micromhos/cm, the dump valve handle can be raised to the up position. (Never mechanically latch the valve in the up position.) This allows freshwater to flow to the storage tank.
10. Observe the permeate flowmeter, and if necessary, readjust the brine restrictor valve to achieve the design freshwater flow.
11. To provide an audible alarm in case the conductivity increases above the setpoint, switch the salinity panel bell selector switch to the normal position.
12. The RO unit can run indefinitely in the normal mode with very little operator input, unless an upset condition is encountered. Normally, the operator needs only to monitor the unit, periodically take data (minimum every 2 hours), and fill out the RO plant logsheet ([Figure 531-13-1](#)).

531-13.3.3.1 The RO plant is designed to operate in a temperature range of 28° to 90° F. The RO plant is not shut down outside of this range since an immersion heater will maintain the lower temperature and higher temperatures are acceptable. Plant capacity can be maintained by varying the operating pressure by adjusting the brine restrictor valve to achieve the desired capacity. Refer to a typical production chart for 9,000-gallon-per-day (gpd) RO unit ([Figure 531-13-2](#)) showing the relation between seawater temperature, operating pressure, and product rate.

531-13.3.4 OPERATING PROBLEMS. The following paragraphs describe abnormal operating conditions that may occur in RO plants. The problems described here may be covered in more detail in one of the equipment TM's. Operators should be thoroughly familiar with the appropriate procedures for these situations before running the RO plant. Operating problems that are adequately described in all TM's may not be discussed here. Electric power failure or motor problems will not be addressed because these are not related to the RO system.

531-13.3.4.1 Feed Flow. Insufficient feed pressure at the suction to the HP pump can result from the following:

- a. The feed shutoff valve is closed.
- b. Strainer or cartridge filters are plugged. Check the differential pressure across each filter. Replace spent cartridge filter elements.
- c. Feed booster pump is not running. Perform electrical check.

531-13.3.4.2 Permeate Flow. If the HP pump is operating at the proper speed, insufficient permeate production can result from the following:

- a. The brine restrictor valve may be incorrectly adjusted so that the pressure on the feed side is too low. Approximately 800 psi is required for the rated permeate production at 70° F. Higher operating pressures may be required to achieve rated output ([Figure 531-13-2](#)).
- b. The RO membranes may be fouled from improper filtration or biological growth. A cleaning cycle may be necessary.
- c. The HP pump valves may be leaking, stuck open, or broken. Observe both the brine and permeate flowmeters. Add the two readings and compare the sum with the rated flow. If the total does not compare, repair or replace the pump valves.

531-13.3.4.3 High Salinity. When this condition occurs, make sure that the dump valve has diverted the permeate to the bilge, and then locate and eliminate the cause of the problem. The following are possible causes of high salinity readings. (Individual plant TM's may have more detailed information).

- a. Ambient seawater temperature may be too high. Remove an element from service by closing the appropriate module control valve and increasing system pressure to the remaining modules.
- b. Salinity meter may be malfunctioning. Make sure that the salinity meter is functioning properly. Refer to the salinity meter TM for test and adjustment procedures.
- c. One or more of the RO membrane elements may have failed. A hand-held conductivity meter may be used to sample the permeate from each individual element. If a failed element is found, isolate it by closing off the module control valve, or secure the unit and replace the failed element. If all samples show high conductivity, clean or replace the membrane elements.

## USS FLETCHER (DD 992) REVERSE OSMOSIS (R/O) PLANT OPERATIONAL DATA SHEET

DATE: \_\_\_\_\_

Time (hr)	Hour Meter (hrs)	Feed Water Temp (° F)	Flowmeter (gal/min)		Pressure Readings (??)							Permeate Water Meter (gal)	Permeate Conductivity	
			Permeate	Brine	Feed	Cart Filter		H/P Pump Feed	H/P Pump Discharge	H/P Brine	R/O Mod Permeate			
						3 dp	20 dp							
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
		33-90	7-9	30-33	30-60	0-5	0-5	5-60	650 -1000	650 -1000	0-45		<1000	
0000														
0200														
0400														
0600														
0800														
1000														
1200														
1400														
1600														
1800	116.8	67	8/8.4	32.5	25	0	0	20	780	720	30	30,450	460	
2000														
2200														
Water Quality Data						Microbiological Data								
Seawater pH			pH											
Time -						From Valve No: _____ Time: _____			Sample Count: _____ Col/100ML					
Time -						From Valve No: _____ Time: _____			Sample Count: _____ Col/100ML					
Note:		SALT DENSITY INDEX DATA (SDI) Initial Flow Rate: _____ Final Flow Rate: _____ Operating Pressure: _____ SDI: _____							ACCUMULATOR PRESSURE Discharge Accumulator: _____ Operating? _____					

Figure 531-13-1 RO Plant Logsheet

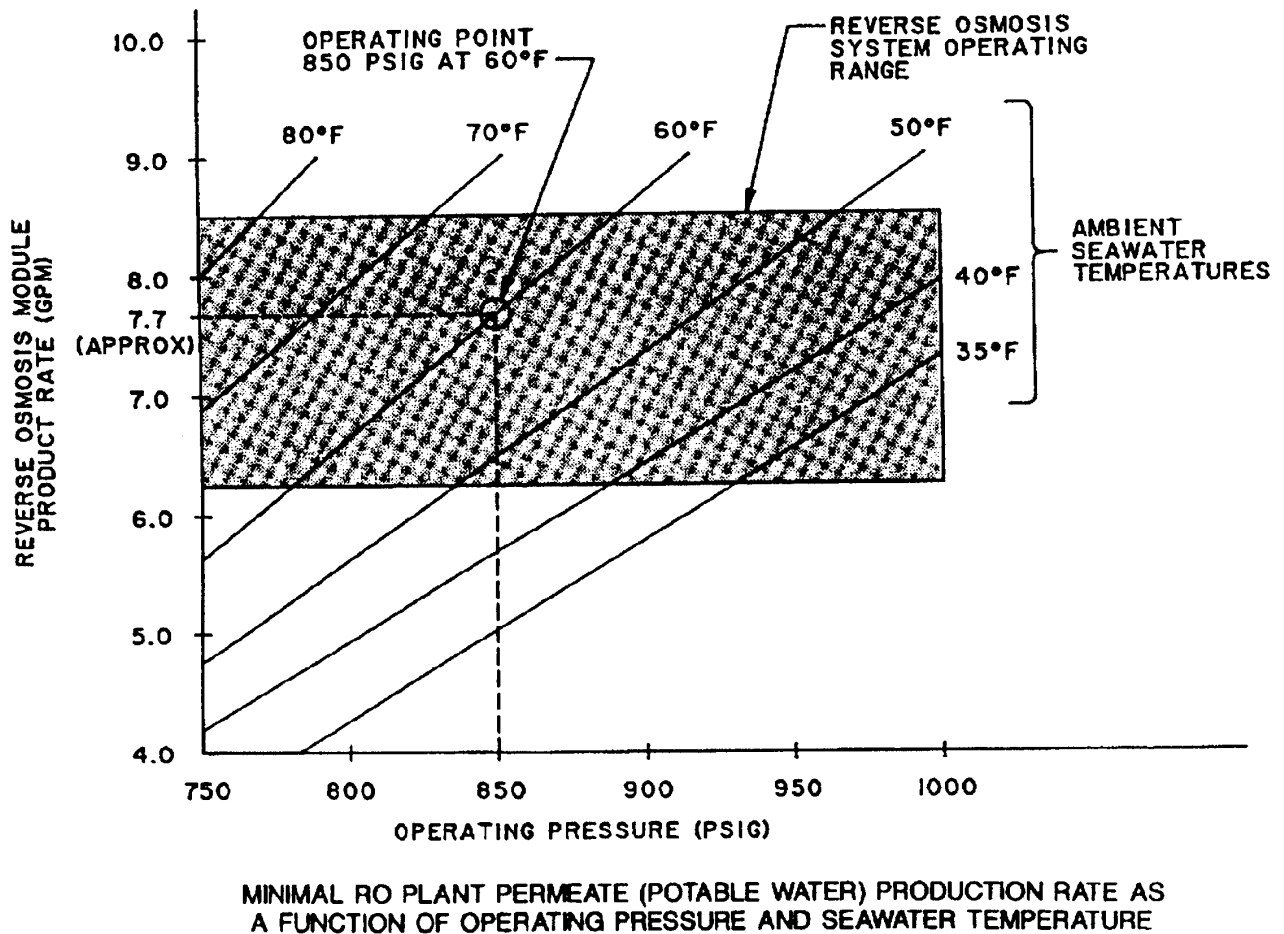


Figure 531-13-2 Production Chart

531-13.3.4.4 Noisy Operation. Excessive noise during operation usually indicates HP pump problems. Possible causes are as follows:

- The HP pump bearings are worn or damaged. Do not operate the pump when this cause has been verified because further damage may occur. Always check crankcase fluid levels before starting pump.
- Insufficient feed pressure to the suction of the HP pump may occur because of the improper valve positioning or plugged filters. Investigate and correct the cause of low suction pressure.

#### 531-13.4 SECURING THE PLANT

531-13.4.1 GENERAL. The following guidelines apply to all RO plants but are not meant to replace the detailed procedures found in the individual plant TM's. All operating personnel shall be thoroughly familiar with these procedures before operating the RO plant.

**531-13.4.2 SHORT-TERM SHUTDOWN.** If the RO unit is to be down for less than 4 hours, it can be secured with seawater in the system, without any additional operations. For this short-term shutdown, open any permeate control valves that were closed and depress the system stop pushbutton on the main control panel.

**531-13.4.3 LONG-TERM SHUTDOWN.** For long-term shutdown, more than 4 hours but less than 14 days, secure the RO unit as follows:

1. Open any permeate control valves that were closed to isolate an RO membrane.
2. Depress the system stop pushbutton on the main control panel.
3. Close the feed shutoff valve, and position appropriate valves to permit freshwater to enter the RO system. If freshwater from the storage tank is to be used for flushing, it shall first be passed through an activated carbon filter to remove the bromine so that the membranes will not be damaged.
4. Fully open the brine restrictor valve.
5. Start unit, and operate for at least 5 minutes to flush out all the seawater.
6. Stop the unit, and open the main circuit breakers.

**531-13.4.4 LAY-UP PROCEDURES.** Refer to the following procedures when the plant is to be secured for more than 14 days or when freezing temperatures are possible during inactive periods.

**531-13.4.4.1 Extended Lay-Up.** During lay-up periods longer than 14 days, rotate the pumps for a few minutes once a week. This prevents corrosion by replenishing the oil coating on the bearings and other lubricated surfaces. Shut off the power after completing this task. For lay-up lasting more than 2 months, operate the RO unit in the flush mode for 2 cycles. Repeat every 2 months.

**531-13.4.4.2 Freezing Temperatures.** If freezing temperatures are expected, drain all water from the RO plant and related piping immediately after shutting down the plant. Make sure that the filter vessels, heater, centrifugal separator, booster pump, HP pump, and RO vessels are drained. Drain the RO pressure vessels. Under these conditions the RO plant need not be flushed periodically.

## **531-13.5 FLUSH MODE**

**531-13.5.1** Flush the RO unit with debrominated freshwater anytime the plant is to be laid up longer than 4 hours or before performing any cleaning operations. Flushing prevents harmful biological growth from forming inside the components, especially on the membrane surface, and allows the cleaning chemicals to function properly. The freshwater flush procedure is described in paragraph [531-13.4.3](#).

## **531-13.6 CLEANING MODE**

**531-13.6.1** Deteriorating membrane performance is normal in RO desalination. Proprietary chemicals are used for removing scales, organic, and particulate deposits. Detailed procedures for cleaning the membranes can be found in the individual TM's.

531-13.6.2 The clean mode cannot be performed until the RO system is flushed with freshwater (paragraph 531-13.4.3). Normally, the flushing period is repeated (two 5-minute flush periods for a timed cycle or 10 minutes for a manually controlled flush) to ensure that all seawater has been flushed out of the RO unit.

### **WARNING**

**Cleaning chemicals are skin and eye irritants. Always wear protective equipment. When mixing these chemicals, add the dry powder to the water carefully; do not add water to the chemical, as this may cause spattering.**

531-13.6.3 After flushing, the chemicals are mixed in either the cleaning system tank or one of the cartridge filter vessels. The chemical solution is circulated throughout the system by opening the recirculation valve or connecting the appropriate hoses. This circulation lasts for 60 minutes; then two flush cycles are used to remove the chemicals. The RO unit can then be restarted for normal operation or remain in the lay-up condition.

## **531-13.7 WHEN TO CLEAN**

531-13.7.1 The need for cleaning is not always obvious because RO performance is affected by temperature, pressure, and salt concentration in total dissolved solids (TDS), as shown in Table 531-13-1. To determine when cleaning is required, consult the individual equipment TM and its production chart, or similar data, which takes into consideration the operating pressure and seawater temperature. A production chart for a 9,000-gpd unit is shown in Figure 531-13-2.

531-13.7.2 If the product rate of the RO unit is not within 25 percent of the operating range shown in the production chart (Figure 531-13-2) for a 9,000-gpd RO unit (or other similar guideline), then membrane cleaning is required.

**Table 531-13-1 VARIABLES AFFECTING PRODUCT CAPACITY AND TDS**

Feedwater (Constant)	Increasing Feedwater (Variable)	Product Results	
		TDS	Capacity
1) Salt concentration and feed pressure	Temperature	Increase	Increase
2) Temperature and feed pressure	Salt concentration	Increase	Decrease
3) Temperature and salt concentration	Feed pressure *	Decrease	Increase

\*Feed pressure shall not be increased above 1,000 psig.

## **SECTION 14. MAINTENANCE**

### **531-14.1 INTRODUCTION**

531-14.1.1 This section provides information on reverse osmosis (RO) unit maintenance. The information in this section (and throughout the chapter) is not intended to replace the detailed maintenance procedures in the indi-

vidual plant technical manuals (TM). Maintenance personnel should be thoroughly familiar with the equipment and all appropriate procedures before beginning any repairs.

## **531-14.2 PREVENTIVE MAINTENANCE**

**531-14.2.1 OVERVIEW.** Most equipment TM's include preventive maintenance procedures, which, if consistently followed, will help provide trouble-free performance for the life of the plant. Some TM's are deficient in this area, so this section summarizes preventive maintenance requirements. Since RO plants vary in design details, the following information is general in nature. Refer to the individual plant TM's whenever possible.

**531-14.2.2 GENERAL.** General instructions on electric motors can be found in **NSTM Chapter 302, Electric Motors and Controllers**. General instructions on both plunger and centrifugal pumps can be found in **NSTM Chapter 503, Pumps**. If planned maintenance system (PMS) is installed, test, inspect, maintain, and overhaul equipment in accordance with maintenance requirement cards (MRC).

**531-14.2.3 STRAINERS.** Clean and inspect the strainer in the feed line before each startup.

**531-14.2.4 FILTERS.** Depending on the characteristics of the seawater feed to the RO plant, one or more stages of the pretreatment system may foul more rapidly than others. The cartridge filters usually do not need to be checked each time the RO plant is started. The differential pressure gage and switch will indicate when the cartridges need to be replaced. Other than replacing the cartridge filters and cover gaskets, the filters require very little attention.

**531-14.2.5 PUMPS.** Inspect all pumps before startup. Check the oil level in the crankcase before startup. Check for unusual noises or vibrations while the pump is running. Add oil as required, and change the oil at regular intervals as called for in the individual TM's.

**531-14.2.5.1** Consult the individual equipment TM's for any procedures other than routine maintenance.

**531-14.2.6 PULSATION DAMPENERS (ACCUMULATORS).** Check the pulsation dampeners for correct charge before starting the RO unit. The correct nonoperating accumulator precharge pressure should be from 400 to 650 psig. Periodic checks will prevent system damage due to incorrect adjustment of precharge. Check for correct functioning of the dampener as follows:

1. When piping and pressure gages are experiencing excessive vibration and noise, test the precharge.
2. After recharging, check for leakage around gas valve.
3. If there is no gas in the bag and fluid appears at the gas valve, disassemble and inspect the bag for leaks.
4. If there are external fluid leaks, tighten all connections. If leakage persists, disassemble and replace faulty parts.
5. If the bladder is damaged, replace it. Check precharge pressure, fluid pressure, system temperature, and operating conditions to isolate and prevent repetition of the problem.

**531-14.2.7 RO MODULE.** The RO pressure vessel, with proper care, requires very little maintenance. The vessel is made from glass-reinforced plastic (GRP), which has excellent corrosion resistance in seawater, or other

suitable corrosion-resistant metal. All the end closure parts may not be of similar material. Any leakage of seawater should be repaired immediately to ensure safe operation.

531-14.2.7.1 Reverse osmosis units with GRP vessels require special handling. A GRP vessel has lower impact resistance than metal and therefore must be protected from rigid clamping, impact, scratches, and abrasion. When the RO module is opened for membrane replacement or inspection, carefully examine the inside diameter of the GRP vessel for any evidence of scratches or abrasions.

531-14.2.7.2 Reverse osmosis membranes require no maintenance other than cleaning with the proprietary chemicals while installed in the vessels or replacement when failed. A defective membrane can be identified by an abrupt increase in product water salinity from that membrane.

531-14.2.8 FLOWMETERS (ROTAMETERS). Check flowmeters before startup to verify that the float has returned to its no-flow condition and that the metering tube is clean for seeing the float. No other maintenance is required unless leaks develop.

531-14.2.9 RELIEF VALVES. Check relief valve (RV) operation once every 3 months by pulling the release lever while the unit is operating. Incorrect operation can be detected by a temperature change in the RV discharge piping or by flow noise or vibration. Check the RV pressure setting once every 12 months in accordance with the RV manual and certification data sheets.

531-14.2.10 LEAK INSPECTION. Check all fittings and connections for leak tightness every time the RO plant is started and once a week on continuously operating plants. Tighten leaking joints, and repair or replace gaskets, if necessary.

## **SECTION 15.**

### **TECHNICAL CONSIDERATIONS**

#### **531-15.1 GENERAL**

531-15.1.1 This section provides methods that will be helpful in determining the causes of poor performance of the reverse osmosis (RO) unit. It will also be helpful in understanding the RO process and design.

#### **531-15.2 EFFECTS OF OPERATING VARIABLES ON PRODUCTION**

531-15.2.1 INCREASING OPERATING VARIABLES. Capacity of the RO unit and product purity, or total dissolved solids (TDS), are affected by the salt concentration in the feed, the seawater temperature, and the feed pressure. The relative change in both product capacity and TDS as a result of an increase in one of the variable is shown in [Table 531-13-1](#).

531-15.2.2 SALT CONCENTRATION. Increasing the salt concentration in the feed increases the TDS in the permeate and decreases the capacity of the unit to produce permeate. This is because higher salinity causes a higher osmotic pressure, reducing the system driving force. To maintain capacity, the system operating pressure is increased, but shall never exceed 1,000 psi.

**531-15.2.3 SEAWATER TEMPERATURE.** The temperature of the feed affects the RO process. As feed temperature increases, product rate will increase as a result of the reduced viscosity of the water and the thermal expansion of the membrane. Permeate production generally changes at the rate of 1 percent for each degree Fahrenheit. For example, an RO plant producing water at the rate of 9,000 gpd at 77°F would produce 8,100 gpd at 67°F.

**531-15.2.4 FEED PRESSURE.** The product rate is directly proportional to the pressure drop across the membrane. Since the permeate-side pressure is constant, the product rate is a direct function of the feed pressure. Although none of the salt flux parameters is directly affected by changes in the feed pressure, there is an indirect effect of pressure on the salt concentration of the permeate. If the pressure decreases, less pure water permeates through the membrane, while the salt flux stays constant. There is, therefore, more salt per unit volume of product water. If the pressure increases, more pure water permeates through the membrane, but the amount of salt passing through does not change. There is, therefore, less salt per unit volume of product water. The effect of pressure on the overall productivity is a result of the sum of the instantaneous productivity and the compaction. Usually, the productivity at any particular time is greater for high-pressure operation than for low-pressure operation.

### **531-15.3 OTHER EFFECTS ON PERMEATE PRODUCTION**

**531-15.3.1 FOULING.** The term fouling is used to indicate a permanent decrease in membrane performance. Fouling usually occurs over a period of time, thereby shortening membrane life. A drop in flux over time is normal. This is a direct result of increased flow resistance due to particulate settlement and scale formation.

**531-15.3.1.1 Particulate Settlement.** The particulate that creates fouling is suspended matter in a finely divided state. It can be composed of clay, silt, finely divided organic and inorganic matter, and microscopic organisms.

**531-15.3.1.1.1 Suspended matter finer than the membrane pore size** can lodge in the pores or be adsorbed on the pore walls. These colloidal particles should be removed from the feed before it enters the RO membrane. Coagulation and filtration can remove these particles. Fortunately, the seawater colloidal particulate content is lower in the open ocean than close to shore. For this reason, most Navy RO units are designed with two-stage filtration only and are normally prohibited from use in harbor and coastal areas. The 1,600-gpd RO units on the MHC class ships are required to operate in coastal areas and therefore are equipped with four-stage filtration with the final cartridge using a 1-micron filter element.

**531-15.3.1.2 Scale Formation.** Seawater contains calcium carbonate,  $\text{CaCO}_3$ . An increase in concentration caused by extracting pure water from the feed can result in the precipitation of  $\text{CaCO}_3$ . This precipitation can cause loss of membrane performance, such as flux decline and polarization.

**531-15.3.1.2.1** The most common methods of preventing or retarding the precipitation of  $\text{CaCO}_3$  from seawater are pH control and commercial chemicals. Navy RO units have neither pH control nor continuous injection of scale inhibitors, but rely on operation at low recoveries for preventing scale buildup.

**531-15.3.1.3 Cleaning.** Periodic cleaning of the RO membrane, determined by high conductivity (over 1,000 micromhos/cm), will remove the particulate settlement and scale that caused the fouling during the normal life (3 years) of the membrane.

531-15.3.2 CHEMICAL DEGRADATION OF MEMBRANES. The polyamide membrane used in the RO system undergoes irreversible chemical changes during its useful life. This reduces membrane flux (capacity) and increases salt passage. Because of these changes, replace membrane elements every 1 to 3 years.



## APPENDIX A

## GLOSSARY

<b>Biological fouling</b>	<b>Fouling caused by accumulating microorganisms (living or dead).</b>
<b>Brine</b>	<b>A saline solution with a concentration of dissolved solids exceeding that of seawater (35,000 ppm). The effluent or reject stream from a seawater desalting plant may be considered as brine.</b>
<b>Chemical feeders</b>	<b>Machines designed to add an exact amount of chemicals to a treatment system.</b>
<b>Chlorination</b>	<b>Adding small amounts of free chlorine, usually to water, to kill harmful organisms in the water and render it safe for drinking.</b>
<b>Chlorinator</b>	<b>A machine for feeding chlorine to a water solution.</b>
<b>Colloid</b>	<b>A liquid containing tiny suspended particles that will not settle over time but can be removed by filtering.</b>
<b>Compaction</b>	<b>In reverse osmosis and ultrafiltration, the decline of flux with time as a result of the applied pressure compressing the membrane.</b>
<b>Contamination</b>	<b>Coating the membrane with contaminants such as algae, slime, bacterial growths, turbidity, etc.</b>
<b>Desalination</b>	<b>The process of removing inorganic salts, usually sodium chloride, from water.</b>
<b>Diffusion</b>	<b>The spontaneous mixing of one substance with another characterized by the movement of molecules of each substance through the empty spaces between the molecules of the other substance. Diffusion is caused by a concentration gradient wherein substances diffuse away from the concentrated region to the less-concentrated region. This process accounts for the fact that air and other gases will slowly pass through most nonporous plastic films. See also permeability.</b>
<b>Empirical</b>	<b>Derived from observation or experiment.</b>
<b>Feed</b>	<b>The input solution (seawater) consisting of both solvent (water) and solute (salt).</b>
<b>Filter</b>	<b>The device in which the filtration operation occurs; it is the body of the filtration.</b>
<b>Filtrate</b>	<b>That which has passed through the filter media, usually the solvent.</b>
<b>Filtration</b>	<b>Separating two phases (solid-liquid, solid-gas, liquid-liquid, liquid-gas, etc.) by passage through a porous material allowing one of the phases to travel through and retaining the other phase in a variably efficient manner.</b>
<b>Flux</b>	<b>The membrane throughput, usually expressed as gallons per square foot of membrane per day. See gpd.</b>
<b>Fouling</b>	<b>Depositing on the membrane surface something that will impede its proper functioning. Sometimes termed blinding.</b>
<b>gpd</b>	<b>Abbreviation for gallons per day.</b>
<b>Laminate</b>	<b>To unite sheets of material by a bonding material usually with pressure and heat (normally used with reference to flat sheets); a product made by so bonding.</b>
<b>Membrane</b>	<b>The thin anisotropic polymer film that is the active separation mechanism in osmosis and reverse osmosis.</b>

## Membrane supports

	Permeable materials used to support the reverse osmosis membranes, normally strong, corrosion, and solvent resistant.
Micron, $\mu$	$10^{-4}$ centimeters (25.4 microns = 0.001 inch = 1 mil).
Module	The combination of a membrane element and its pressure container.
Osmosis	Self-diffusion through a semipermeable membrane of a solvent due to the differential pressure between two solutions of differing concentrations. The natural tendency to equalize concentrations will result in a flow of solvent from the least concentrated solution to the more concentrated solution. The tendency is to dilute concentration.
Permeability	The passage or diffusion of water through a barrier without physically or chemically affecting it. The rate of such passage is usually expressed as the quantity of the permeate per unit area, thickness, time, and driving force.
Permeable	Having physical strength and appearing solid but capable of allowing certain materials to pass through virtually unimpeded.
Permeate	That which passes through the membrane.
pH	A measure of the hydrogen ion concentration in solution. Numerically, it is the negative logarithm of the hydrogen ion concentration, scaled 0 to 14. Zero to 7 represents relative acidity, 7 being neutral, and 7 to 14 represents relative alkalinity.
Polymer	A chemical compound with many repeating units of organized molecular blocks.
ppm	Abbreviation for parts per million; unit of salt concentration.
Precipitate	Material that separated out of a solution in the form of a solid; separating out such solid by physical or chemical means.
Product	The desired separated output.
psi	Abbreviation for pounds per square inch; a unit of hydraulic pressure.
Rejection	The amount of material not allowed to pass through a membrane.
Reverse osmosis	The reverse of the natural osmosis achieved by external application of sufficient reverse pressure to cause the solvent to flow in its unnatural direction, that is from the more concentrated solution to the dilute solution.
Saline water	Generally water having more than 1,000 ppm dissolved salts.
Salinity	The total amount of solids (in grams) contained in one kilogram of seawater when all carbonate has been converted to oxide, all bromide and iodide replaced by chloride and all organic matter completely oxidized.
Salt rejection (SR)	The salt rejection expressed as a percentage is defined as $SR = ((\text{Salt conc. in feed} - \text{salt conc. in effluent}) / (\text{Salt Conc. in feed})) \times 100$
Scale	A coating that forms on working surfaces of a system because of the precipitation or crystallization of salt compounds or solids.
Sediment	Usually the coarse material (such as silt, sand, etc.) that settles quite rapidly because of its high specific gravity.
Semipermeable	A membrane that is selective to certain components membrane of a solution (ordinarily the solvent) allowing them to pass through the membrane while one or more other components cannot do so.
Solute	The solid (typically salt) that is dissolved in a solvent to form a solution.

<b>Solvent</b>	<b>The liquid (typically water) in which salts or solutes are dissolved to form a solution.</b>
<b>Spiral</b>	<b>A winding line or path that gets ever further away from a central starting point around which it winds.</b>
<b>Suspended solids</b>	<b>Particle matter dispersed in a solution that will settle out in a reasonable time when the solution is in a quiescent state.</b>
<b>TDS</b>	<b>Abbreviation for total dissolved solids.</b>



## **REAR SECTION**

### **NOTE**

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